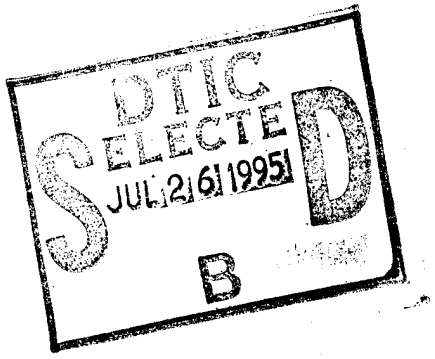

EVALUATION OF SAMPLE HELICOPTER TAIL ROTOR PITCH LINK BEARINGS BY DYNAMIC TESTING USING SIMULATED LOAD/MOTION CONDITIONS

FRC Report P253

December 3, 1992

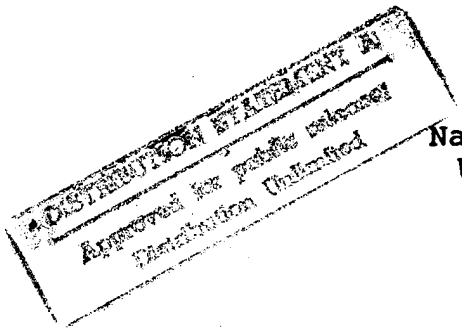

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

This report describes the testing performed on helicopter rotor pitch link bearings. The purpose of the testing was to evaluate a new liner material situated between the ball and race of each bearing. The bearing material would be expected to endure a severe simultaneous cyclic loading and oscillatory motion, as is experienced in bearings of present day helicopters when they are maneuvered.

Twenty-two bearings were submitted for test by the Naval Air Development Center (NADC) under Contract N62269-90-C-0247. A total of 9600 hours of bearing testing was scheduled for 12 of the 22 bearings. In the event of premature failures, the other 10 bearings were to be used. Six of the 12 bearings would be subjected to a Type I testing and the other six to a Type II testing program. The difference between the Type I and Type II testing was the level of load applied to the bearings and the angle of motion through which the bearings were oscillated.

A Franklin Research Center (FRC) Instron Lawrence Dynamic Test System was used to load the test bearings, and the mechanism to provide oscillatory motion to the test specimens was designed and built by FRC. This mechanism also generated an electrical signal to drive the Instron machine at the proper cyclic load rate. A list of data acquisition instruments is provided as Appendix A.

2.0 RECEIPT OF TEST SPECIMENS

Twenty-two bearings were received from NADC. Each bearing was sealed in a brown paper bag. Each bag was marked with a serial number and the following information:

Southwest Products Co.
83176
SWVR-8-204
Monoball® Bearings
Sept. 13, 1991

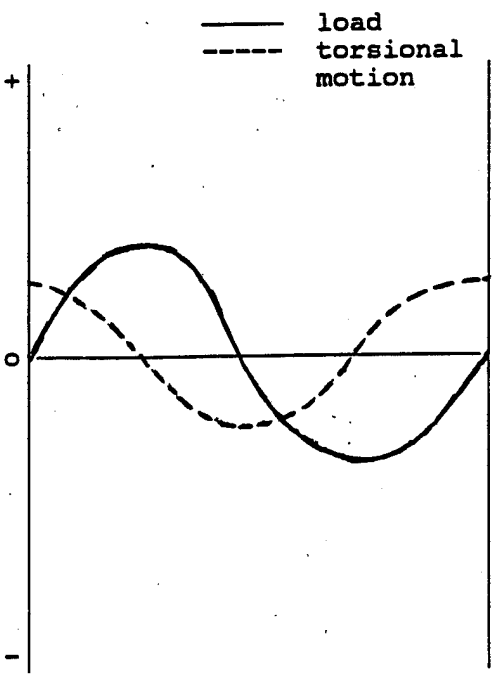
Serial numbers of bearings received:

0001	0013
0002	--
0003	0015
0004	0016
0005 (Bag was open)	0017
--	0018
0007	0019
0008	0020
0009	0021
0010	0022
0011	0023
0012	0024

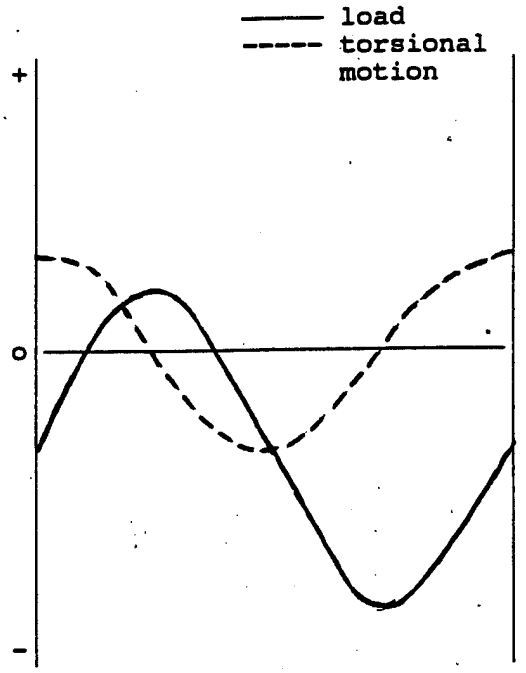
3.0 PROGRAM DESCRIPTION

A synopsis of the program is outlined below. The complete NADC Work Statement is included as Appendix B.

Although 22 bearings were shipped to FRC by NADC, the test plan was based on only 12 of the 22 bearings being tested. Each was to run until it failed. Fewer than 12 bearings were to be tested if the bearings exceeded the expected 800 hours of dynamic testing, and a greater number would be tested if the bearings failed before 800 hours of testing were achieved. Bearing failure was stipulated as bearing wear in excess of 0.008 inch. Each of six bearings were to be subjected to a Type I testing, consisting of a radial load of $\pm$ 900 pounds applied in a cyclicly reversing tension and compression mode, while simultaneously applying an angular torsional motion of $\pm$ 10 degrees. The other six bearings were to undergo a Type II testing, similar to Type I above except that the loading would be -600 $\pm$ 1000 pounds, with $\pm$ 6 degrees of oscillatory motion. The radial load and angular motion was to be applied sinusoidally and 90 degrees out of phase as depicted below:



Type I



Type II

A cyclic rate of 700 cycles per minute was specified. In addition to the above requirements, all tests were to be conducted at a room temperature of 75° ± 15°F, relative humidity of 90 percent or less, and at ambient barometric pressure. Other testing particulars including wear, temperature, and torque measurement information can be found in the NADC Statement of Work of Appendix B.

4.0 BEARING TEST PREPARATION SEQUENCE

Prior to conducting a test run (a test run consisted of two specimens tested concurrently), the following preparations were made:

A. Two of the twelve bearings (starting with Serial Number 0001 and 0002) were pressed into heat treated steel housings with a 0.0005 to 0.0015 inch interference fit. Figures 1 and 2 show a bearing before and after it is pressed into a housing.

B. Following installation in the housing, the bearing's outer ring side face was engraved at the maximum load location. This was done to permit post test sectioning of the bearing through the maximum load plane so that accurate liner thickness measurements could be conducted under a microscope.

C. After carefully supporting, aligning, and positioning each test bearing within a clevis, a close tolerance aircraft pin was pressed into the bearing. Needle roller bearings were inserted into the sides of the clevis to support the shaft and permit oscillatory motion of the test bearing. Flat washers and retaining rings prevented excessive sidewise movement.

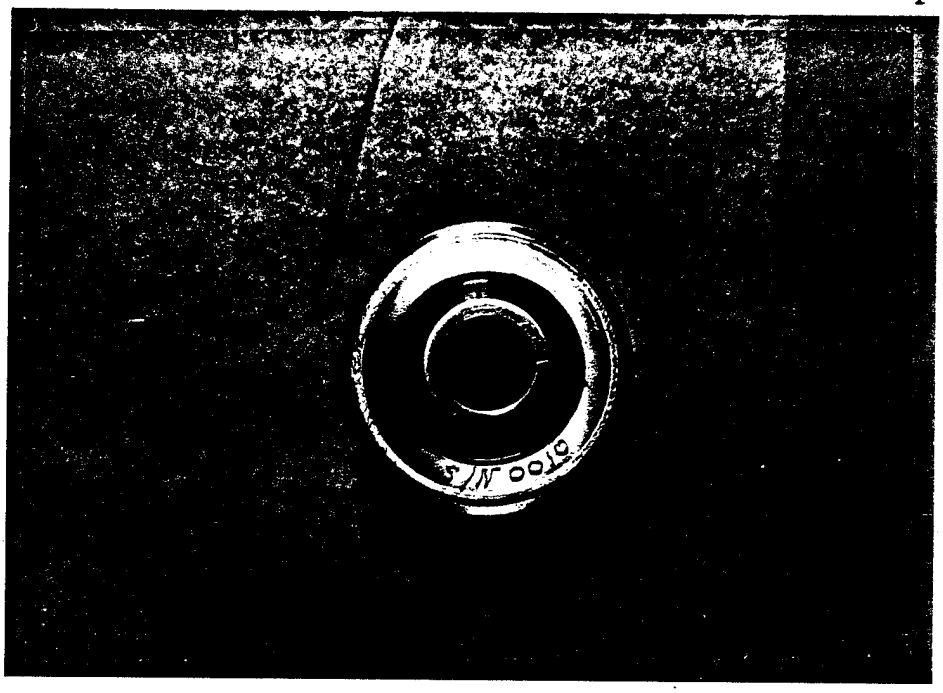


Figure 1. Typical Test Bearing Before Being Pressed Into Housing.

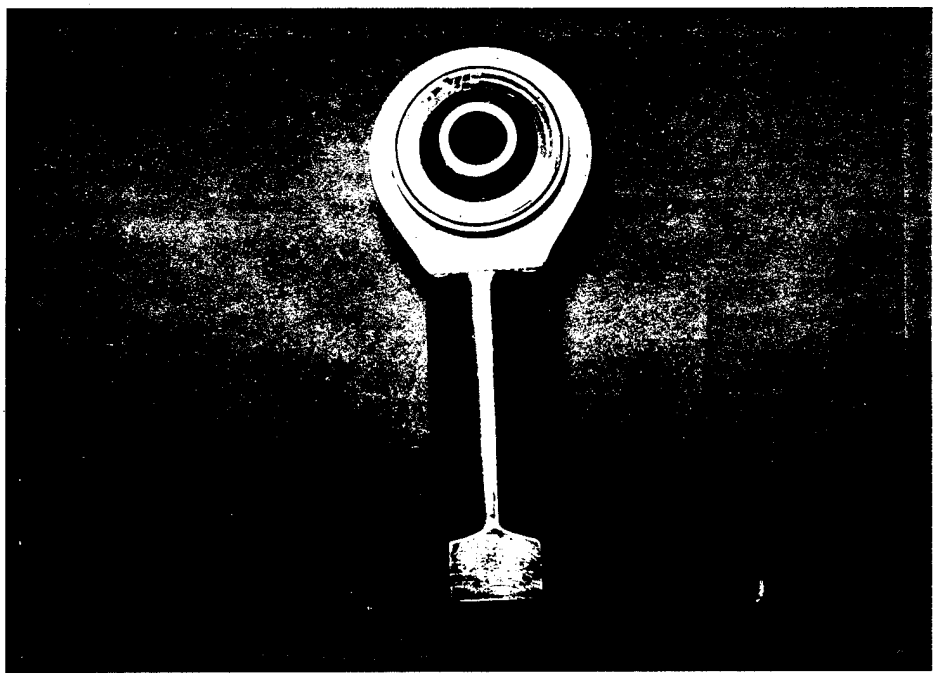


Figure 2. Typical Test Bearing After it is Pressed Into Housing.

D. A tie rod was used to connect the two clevises together as an assembly. This assembly was then installed in the Instron test machine.

E. Crank arms were connected to the bearing shafts and to a connecting rod, which was driven by an electric motor crank. An overall view of the assembly installed in the test machine is presented as Figure 3.

Before connecting the crank arms to the bearing shafts, and prior to the start of each test run, a breakaway torque test was performed on each of the specimens. The bearings were loaded with a tensile force of 200 pounds for a minimum of 15 minutes, before conducting these tests. Wear measurements were also taken before the start of each test run to establish a zero wear reference point. During the testing period, wear measurements were taken once per day with the bearings in tension under a 200 pound load.

Copper tubes (1/4 inch size) shown in the photo of Figure 3 are water contamination lines terminated above both sides of each test specimen. The lines were connected to a metering apparatus which allowed approximately 30 ml per hour of distilled water to flow over the test specimens. A solenoid controlled valve gravity fed system was operated for six hours of each working day that a test run was in progress.

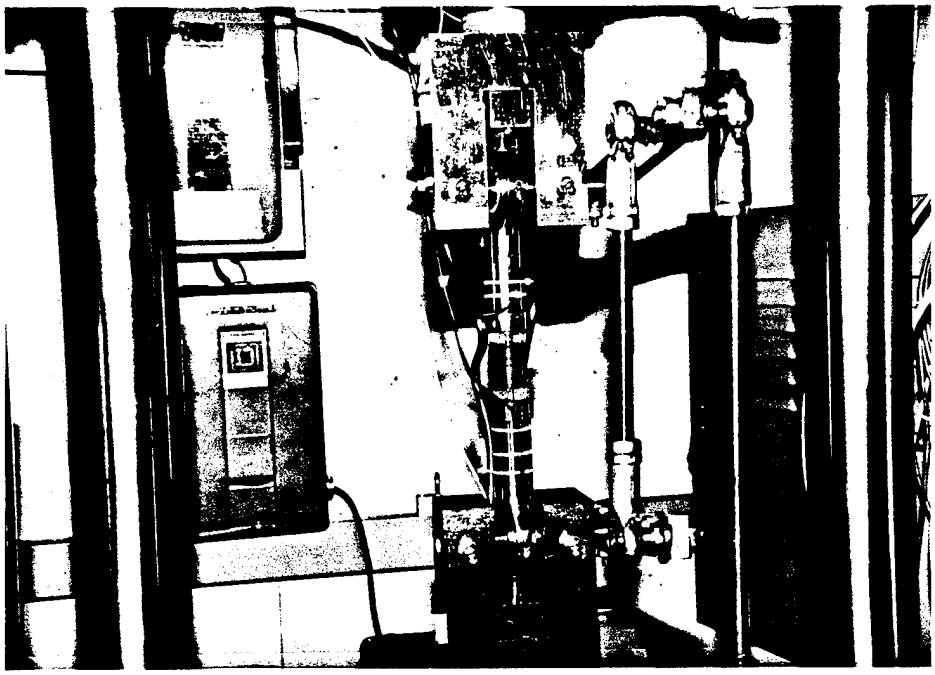


Figure 3. Overall View of Assembly Installed in the Test Machine.

5.0 TEST RESULTS

5.1 TEST RUN NO. 1, BEARINGS 0001 AND 0002

Test specimens numbered 0001 and 0002 were inserted in the test assembly, as described in Section 3, and connected to the load cell and actuator of the dynamic test machine. Specimen 0001 was installed in the upper clevis close to the load cell and 0002 was installed close to the actuator in the lower clevis.

Prior to starting the test, the breakaway torque for Bearings 0001 and 0002 was measured and found to be 22.5 and 27.5 pound inches, respectively.

At approximately 24 hours elapsed running time, bearing wear was 3.8 mils for specimen 0001 and 4.8 mils for specimen 0002. Also, at this time, gray colored powder was detected collecting on the top surface of the lower clevis and on the surface of the lower proximitor holder.

After 47.0 hours elapsed time a substantial accumulation of gray powder was observed on the same areas including flakes of gray material. At this time the wear had increased to 5.0 mils and 5.7 mils for the two bearings.

When the bearings were checked for wear after 119.1 hours, Specimen 0002 had 19.5 mils of wear and the wear on Specimen 0001 was 7.3 mils. Black material was clinging to both sides of the upper and lower test bearings. A piece of the material,

relatively large and curve shaped, was removed from the black material located on the side of Bearing 0002. The test was terminated after about 143 hours elapsed time because both bearings had exceeded the failure criterion of 8 mils wear. It was subsequently revealed that the curved piece of material was a piece of the liner that had been forced out of the bearing. The black substance was mainly grease from the end roller bearings.

The data listed in Table 1 was recorded during that period of time when the machine was shut down to measure bearing wear. Daily bearing housing temperatures recorded during actual load/oscillating operation were reduced from the datalogger and are presented in Table 2. The post test breakaway torque measurements were 15.0 pound inches for bearing 0001 and 40.0 pound inches for bearing 0002.

Bearing 0001 was sectioned through the maximum load zone. After the bearing was cross-sectioned vertically, it was evident that remnants of the liner were present on only one side of the outer ring, as indicated in Figure 4. Grease obscured any damage on the half of the bearing without the liner, but cracking of the liner on the other half was obvious. After the sections were degreased the linerless side appeared roughed from adhesive wear incurred during interaction with the ball, as shown in Figure 5.

Table 1.
TEST DATA TABULATIONS
RUN NO. 1
BEARING NUMBERS 0001 & 0002

BEARING NO. 0001:

Date	Clock Time	Elapsed* Time (h)	Ambient Temp(°F)	Bearing** Housing Temp(°F)	Proximitor Reading (Vdc)	Wear (in)	RH(%)
3/4/92	0905	-	78	77	- 8.846 (54.6 mils)	0.0	≈ 70
3/4/92	0930	0.0	Test Started	-	-	-	-
3/5/92	0900	23.5	80	127	- 9.524 (58.4 mils)	0.0038	≈ 70
3/6/92	0830	47.0	79	138	- 9.728 (59.6 mils)	0.0050	≈ 70
3/9/92	0835	119.1	79	84	-10.137 (61.9 mils)	0.0073	≈ 70
3/10/92	0805	142.6	81	96	-10.875 (66.0 mils)	0.0114	69

BEARING NO. 0002:

Date	Clock Time	Elapsed* Time (h)	Ambient Temp(°F	Bearing** Housing Temp(°F	Proximitor Reading (Vdc)	Wear (in)	RH(%)
3/4/92	0905	-	78	77	- 9.542 (60.5 mils)	0.0	≈ 70
3/4/92	0930	0.0	Test Started	-	-	-	-
3/5/92	0900	23.5	80	110	-10.412 (65.3 mils)	0.0048	≈ 70
3/6/92	0830	47.0	79	114	-10.572 (66.2 mils)	0.0057	≈ 70
3/9/92	0835	119.1	79	86	-13.015 (80.0 mils)	0.0195	≈ 70
3/10/92	0805	142.6	81	107	-12.677 (78.4 mils)	0.0179	69

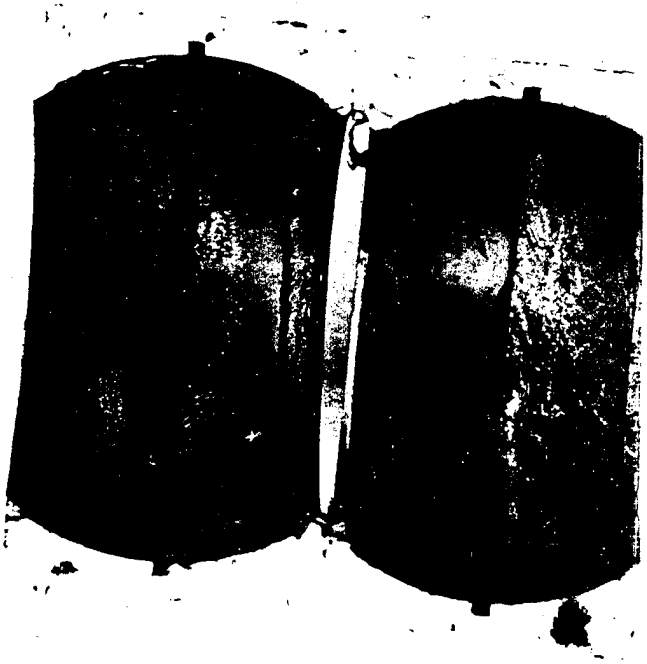
*Elapsed time includes approximately 30 minutes of down time each day to measure bearing wear, clean, and lubricate mechanism.
**Bearing housing temperatures were recorded when machine was off to measure bearing wear.

Table 2. Temperature-Time Data

Run No. 1, Bearings 0001 and 0002

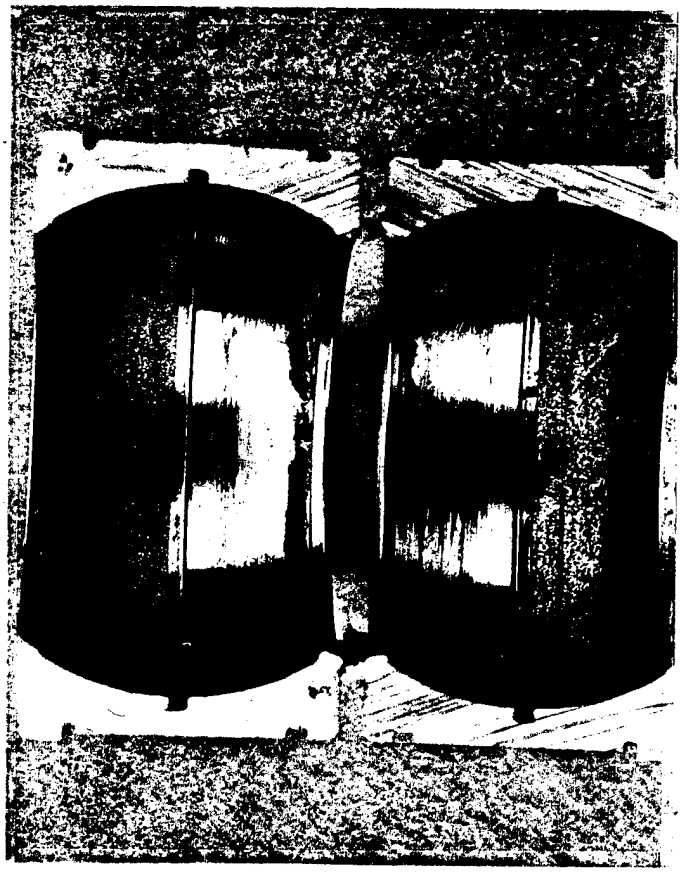
Date	Time	Elapsed Time(h)	Temp. (°F) Bearing No. 0001	Temp. (°F) Bearing No. 0002
3/4/92	0930	Start of Test	-	-
3/4/92	1047	1.3	143	153
3/5/92	0741	22.2	150	123
3/6/92	0735	46.1	148	130
3/7/92	0748	70.3	150	110
3/8/92	0700	93.5	93	82
3/9/92	0720	117.8	95	95
3/10/92	0650	141.3	95	114

The highest temperature recorded by the datalogger was 165°F at 2220 hours on 3/4/92, for Bearing 0001. At approximately the same time, Bearing 0002 achieved its highest temperature of 156°F.



2X

Figure 4. Macrograph of Bearing 0001 showing the inside surface of the outer component (i.e., the socket) of the bearing after it had been vertically cross sectioned. Remnants of liner material are present on one side (in the center above) of the socket, and grease masks the side without the liner.



2X

Figure 5. Macrograph of Bearing 0001 after it was degreased, showing the wear that had taken place on one side of the socket after the liner had disintegrated. The sections are oriented the same as in Figure 4, and the top and bottom are situated as during the test.

It is clear that the test had run for a significant time after the liner had disintegrated and that, in the absence of the liner, the grease that had leaked into the bearing from the end roller bearings had been only partially effective in protecting the contact surfaces.

Bearing 0002 was not sectioned because it appeared to have been completely stripped of its plastic liner material.

5.2 TEST RUN NO. 2, BEARINGS 0003 AND 0004

In the second run, test specimens numbered 0003 and 0004 were installed in the test assembly in the same manner as the bearings of the previous run. Specimen 0003 was assembled in the upper and Specimen 004 was installed in the lower clevis.

The pre-test breakaway torque was 47 pound inches for Bearing 0003 and 45 pound inches for Bearing 0004.

After 21.7 hours of testing, Bearing Specimen 0003 developed 5.7 mils of wear while Specimen 0004 experienced 4.1 mils of wear. Twenty-four hours later (45.5 hours elapsed time) the test was found shut down. Also, it was discovered that the bearing liner had been pushed out of Specimen 0003. At this time, the wear measurement for this failed bearing was 18.1 mils. Even though Specimen 0004 had only 5.4 mils of wear, the test was not continued because the failed bearing would have had to be removed and another bearing substituted in its place. Testing a new

bearing with a partially worn bearing would not have been practical.

Data recorded manually while measuring bearing wear during the second run are tabulated in Table 3, and daily running temperature-time data were reduced from datalogger chart paper and tabulated as Table 4.

The breakaway torque tests following Run No. 2 were inadvertently omitted. However, they were conducted after Run No. 1 and the results were not meaningful due to the absence of liner material.

5.3 TEST RUN NO. 3, BEARINGS 00797 AND 01893

The specimens tested in the third run were special in the sense that they were not of the original 12 bearing specimens scheduled for test. Both bearings were inscribed with the same part number and manufacturer's number as follows:

78286SOCNSB5085-101
MFR-15860

One bearing was inscribed with SERNO 00797 and the other with SERNO 01893. These two bearings received via Priority Mail from Naval Air Warfare Center Aircraft Division, were to provide a means of comparison with the bearings tested in Runs 1 and 2. Since specimens 0001 through 0003 had failed, and Specimen 0004 was less than three mils from failing when the second run was terminated, it was questioned whether the testing was too rigorous.

Table 3.

TEST DATA TABULATIONS
RUN NO. 2
BEARING NUMBERS 0003 & 0004

BEARING NO. 0003:

Date	Clock Time	Elapsed* Time (h)	Ambient Temp(°F)	Bearing** Housing Temp(°F)	Proximitor Reading (Vdc)	Wear (in)	RH(%)
4/7/92	1000	-	77	79.3	- 8.527 (52.9 mils)	0.0	-
4/7/92	1045	0.0	Test Started	-	-	-	-
4/8/92	0820	21.7	80	102.5	- 9.553 (58.6 mils)	0.0057	54
4/9/92	0810	45.5	78	80.9	-11.775 (71.0 mils)	0.0181	51

BEARING NO. 0004:

Date	Clock Time	Elapsed* Time (h)	Ambient Temp(°F	Bearing Housing Temp(°F	Proximitor Reading (Vdc)	Wear (in)	RH(%)
4/7/92	1000	-	77	78.7	- 8.932 (55.1 mils)	0.0	-
4/7/92	1045	0.0	Test Started	-	-	-	-
4/8/92	0820	21.7	80	120.7	- 9.713 (59.5 mils)	0.0041	54
4/9/92	0810	45.5	78	81.8	- 9.904 (60.5 mils)	0.0054	51

Because of 18 mils wear in upper bearing, testing could not be continued for Specimen 0004.

*Elapsed time includes approximately 30 minutes of down time each day to measure bearing wear, clean, and lubricate mechanism.
**Bearing housing temperatures were recorded when machine was off to measure bearing wear.

Table 4. Temperature-Time Data

Run No. 2, Bearings 0003 and 0004

Date	Time	Elapsed Time(h)	Temp. (°F) Bearing No. 0003	Temp. (°F) Bearing No. 0004
4/7/92	1045	Start of Test	-	-
4/8/92	0722	20.6	108	121
4/9/92	0741	44.9	80	80

The highest temperature of 188°F occurred at 0254 hours on 4/9/92, for Bearing 0003. For Bearing 0004 the highest temperature was 132°F at 0830 hours on 4/8/92.

The physical dimensions of the new set of bearings were the same as the other bearings being tested. However, it was noticed that, when compared to the other bearings, the ball could be more easily swiveled in the race of each bearing.

Test specimen numbered 00797 was installed in the upper clevis and Specimen 01893 was assembled in the lower clevis on the test assembly. There was a significant difference in breakaway torque between these bearings and the bearings of the previous two test runs. The breakaway torque for specimens 00797 and 01893 were much lower. Results of the first three runs are as follows:

Bearing No.	Pretest Breakaway Torque (lb-in)
0001	22.5
0002	27.5
0003	47.0
0004	45.0
00797	7.5
01893	12.5

Unlike the first two test runs, where the bearing wear was 5 and 6 mils for bearings 0001 and 0002 and 18 and 5 mils of wear for bearings 0003 and 0004 after two days of testing, the bearings tested in this third run experienced only 1.3 and 0.4 mils of wear during approximately the same time period. The

maximum wear over a total running period of 763 hours for bearings 00797 and 01893 was 4.2 and 4.0 mils, respectively.

Bearing wear fluctuated up and down beginning on the sixth day of testing. The largest fluctuation was 1.4 mils for Specimen 00797 and 2.2 mils for Specimen 01893. It is not certain why these fluctuations occurred. Temperature differences, ball position within the race of the bearing, and lateral position of the bearing shaft and housing with respect to the sensor could have influenced the measurements. Data for run number 3 (Table 5) were taken at those times when bearing wear was being measured. The actual operational temperature-time data (Table 6) were reduced from the datalogger.

The test run was terminated after 763 hours when too much play developed between the pin and the adapters that couple the machine actuator to the bottom clevis. This play prevented proper loading of the specimens.

The after-test breakaway torque was 32.5 pound inches for Bearing 00797 and 40 pound inches for Bearing 01893.

5.4 TEST RUN NO. 4, BEARINGS 0005 AND 0008

Following the testing of Run No. 3 and the fabrication of new machine parts, FRC was instructed by NADC to test two additional bearings from the original lot of 12 specimens.

For test run No. 4, bearing specimens numbered 0005 and 0008 were selected. Bearing numbers 0006 and 0007 were not used

Table 5.

TEST DATA TABULATIONS
RUN NO. 3
BEARING NUMBERS 00797 & 01893

BEARING NO. 00797:

Date	Clock Time	Elapsed* Time (h)	Ambient Temp(°F	Bearing** Housing Temp(°F	Proximitor Reading (Vdc)	Wear(mils)	RH(%)
5/28/92	1200	0.0	75	75.3	- 9.404 (57.7 mils)	0.0	61
5/29/92	0830	20.5	76	104.4	- 9.620 (59.0 mils)	1.3	60
5/30/92	1530	51.5	77	120.7	- 9.629 (59.0 mils)	1.3	63
6/1/92	0830	67.5	77	115.2	- 9.683 (59.3 mils)	1.6	74
6/2/92	0810	91.0	76	115.2	- 9.716 (59.5 mils)	1.8	73
6/3/92	0810	115.0	77	102.2	- 9.968 (60.9 mils)	3.2	72
6/4/92	0845	139.5	77	105.0	- 9.790 (59.9 mils)	2.2	74
6/5/92	0830	163.5	70	101.8	- 9.881 (60.4 mils)	2.7	77
6/8/92	0800	235.0	79	101.3	-10.132 (61.8 mils)	4.1	85
6/9/92	0815	259.0	79	99.8	-10.132 (61.8 mils)	4.1	83
6/10/92	0815	283.0	77	95.4	- 9.892 (60.5 mils)	2.8	71
6/11/92	0832	307.0	75	93.0	- 9.858 (60.3 mils)	2.6	67
6/12/92	0830	331.0	76	93.0	- 9.912 (60.6 mils)	2.9	72
6/15/92	0830	403.0	76	77.2	- 9.814 (60.0 mils)	2.3	76
6/16/92	0825	427.0	77	96.0	- 9.968 (60.9 mils)	3.2	73

Table 5.(Cont.).
TEST DATA TABULATIONS
RUN NO. 3
BEARING NUMBERS 00797 & 01893

BEARING NO. 00797:

Date	Clock Time	Elapsed* Time (h)	Ambient Temp(°F	Bearing** Housing Temp(°F	Proximitor Reading (Vdc)	Wear(mils)	RH(%)
6/17/92	0815	451.0	77	92.0	- 9.814 (60.0 mils)	2.3	72
6/18/92	0815	475.0	76	92.0	- 9.951 (60.8 mils)	3.1	71
6/19/82	0815	499.0	76	92.0	- 9.865 (60.3 mils)	2.6	77
6/22/92	0810	571.0	73	91.0	- 9.970 (60.9 mils)	3.2	67
6/23/92	0815	595.0	73	88.0	- 9.828 (60.1 mils)	2.4	62
6/24/92	0815	619.0	77	93.0	- 9.992 (61.0 mils)	3.3	74
6/25/92	0815	643.0	76	99.0	-10.144 (61.9 mils)	4.2	76
6/26/92	0830	667.0	76	84.0	- 9.905 (60.6 mils)	2.9	77
6/29/92	0810	739.0	75	86.0	-10.069 (61.1 mils)	3.4	75
6/30/92	0815	763.0	77	90.0	- 9.892 (60.0 mils)	2.3	79

*Elapsed time includes approximately 30 minutes of down time each day to measure bearing wear, clean, and lubricate mechanism.
**Bearing housing temperatures were recorded when machine was off to measure bearing wear.

Table 5 (Cont.)
TEST DATA TABULATIONS
RUN NO. 3
BEARING NUMBERS 00797 & 01893

BEARING NO. 01893:

Date	Clock Time	Elapsed* Time (h)	Ambient Temp(°F	Bearing** Housing Temp(°F	Proximitor Reading (Vdc)	Wear(mils)	RH(%)
5/28/92	1200	0.0	75	74.9	- 8.886 (56.9 mils)	0.0	61
5/29/92	0830	20.5	76	105.8	- 8.927 (57.1 mils)	0.2	60
5/30/92	1530	51.5	77	121.52	- 8.963 (57.3 mils)	0.4	63
6/1/92	0830	67.5	77	109.38	- 9.020 (57.6 mils)	0.7	74
6/2/92	0810	91.0	76	107.77	- 9.024 (57.6 mils)	0.7	73
6/3/92	0810	115.0	77	121.89	- 9.297 (59.1 mils)	2.2	72
6/4/92	0845	139.5	77	120.0	- 9.230 (58.8 mils)	1.9	74
6/5/92	0830	163.5	70	114.22	- 9.154 (58.4 mils)	1.5	77
6/8/92	0800	235.0	79	112.20	- 9.564 (60.6 mils)	3.7	85
6/9/92	0815	259.0	79	108.15	- 9.613 (60.9 mils)	4.0	83
6/10/92	0815	283.0	77	103.56	- 9.227 (58.8 mils)	1.9	71
6/11/92	0832	307.0	75	92.0	- 9.226 (58.8 mils)	1.9	67
6/12/92	0830	331.0	76	93.53	- 9.195 (58.6 mils)	1.7	72
6/15/92	0830	403.0	76	78.4	- 9.272 (59.1 mils)	2.2	76
6/16/92	0825	427.0	77	93.0	- 9.345 (59.3 mils)	2.4	73

Table 5 (Cont.).

TEST DATA TABULATIONS
RUN NO. 3
BEARING NUMBERS 00797 & 01893

BEARING NO. 01893:

Date	Clock Time	Elapsed* Time (h)	Ambient Temp(°F	Bearing** Housing Temp(°F	Proximitor Reading (Vdc)	Wear(mils)	RH(%)
6/17/92	0815	451.0	77	97.0	- 9.262 (59.0 mils)	2.1	72
6/18/92	0815	475.0	76	94.0	- 9.368 (59.5 mils)	2.6	71
6/19/82	0815	499.0	76	94.0	- 9.345 (59.3 mils)	2.4	77
6/22/92	0810	571.0	73	97.0	- 9.481 (60.1 mils)	3.2	67
6/23/92	0815	595.0	73	89.0	- 9.236 (58.8 mils)	1.9	62
6/24/92	0815	619.0	77	94.0	- 9.330 (59.2 mils)	2.3	74
6/25/92	0815	643.0	76	97.0	- 9.560 (60.6 mils)	3.7	76
6/26/92	0830	667.0	76	86.0	- 9.294 (59.0 mils)	2.1	77
6/29/92	0810	739.0	75	84.0	- 9.386 (59.6 mils)	2.7	75
6/30/92	0815	763.0	77	89.0	- 9.267 (59.0 mils)	2.1	79

*Elapsed time includes approximately 30 minutes of down time each day to measure bearing wear, clean, and lubricate mechanism.
**Bearing housing temperatures were recorded when machine was off to measure bearing wear.

Table 6. Temperature-Time Data
Run No. 3, Bearings 00797 and 01893

Date	Time	Elapsed Time	Temp. (°F) Bearing No. 00797	Temp. (°F) Bearing No. 01893
5/28/92	1200	Start of Test	-	-
5/29/92	0740	19.7	125	117
5/30/92	0800	44.0	125	120
5/31/92	0843	68.7	125	125
6/1/92	0750	91.8	119	123
6/2/92	0718	115.3	118	117
6/3/92	0802	140.0	122	103
6/4/92	0731	163.5	120	105
6/5/92	0753	188.1	118	103
6/6/92	0725	211.4	114	102
6/7/92	0743	235.7	115	102
6/8/92	0804	260.1	113	102
6/9/92	0731	283.5	103	100
6/10/92	0813	308.2	103	97
6/11/92	0736	331.6	93	95
6/12/92	0807	356.1	92	92
6/13/92	0734	379.6	104	106
6/14/92	0706	403.1	98	105
6/15/92	0748	427.8	77	77
6/16/92	0700	451.0	97	102
6/17/92	0744	475.7	92	95
6/18/92	0716	499.3	95	95
6/19/92	0728	523.5	94	94
6/20/92	0839	548.6	95	95
6/21/92	0747	571.8	95	95
6/22/92	0747	595.8	95	92
6/23/92	0852	620.9	93	93
6/24/92	0801	644.0	95	95
6/25/92	0713	667.2	96	99
6/26/92	0754	691.9	85	85
6/27/92	0838	716.6	91	91
6/28/92	0835	740.6	88	95
6/29/92	0725	763.4	85	88
6/30/92	0807	788.1	89	92

The highest temperature of 128°F occurred at 1335 hours on 6/1/92, for Bearing 00797. For Bearing 01893 the highest temperature was 136°F at 1840 hours on 6/1/92.

because none of the bearings were engraved with a number 0006, and, bearing 0007 had been installed for test, but was removed from the clevis when the decision was made to test the special bearings of run No. 3.

The pretest breakaway torque was 27.5 pound inches for Bearing 0005 installed in the upper clevis, and 25.0 for Bearing 0008 installed in the lower clevis. Seventeen hours after the test was started the two bearings failed. Both bearings were stripped of liner material. Pieces of the curved liner were found on surfaces of the assembly and machine. Specimen wear was 27 mils for bearing 0005 and 31 mils for bearing 0008. Only one wear measurement had been taken after starting the test run, due to early failure of both bearings. Hourly temperatures of the bearing housings were reduced from the datalogger chart and tabulated. Temperatures at both bearing housings climbed to well over 300°F after 12 or 13 hours of testing as the bearings failed. The wear measurement results and actual temperature-time data are listed in Table 7. The post test breakaway torque measurement values were 87.5 and 52.5 pound inches for bearings 0005 and 0008, respectively.

Figure 6 is a temperature vs time graph for bearings 0001-0004, 0005, and 0008, showing all bearings failing prematurely. Bearings 00797 and 01893 of test run number three were combined with the failed bearings and graphed as Figure 7.

None of the bearings were sectioned after the first tested bearing (0001) was sectioned, because the liners were stripped

Table 7.

TEST DATA TABULATIONS
RUN NO. 4
BEARING NUMBERS 0005 & 0008

BEARING NO. 0005:

Date	Clock Time	Elapsed Time (h)	Ambient Temp(°F)	Bearing Housing Temp(°F)*	Proximitor Reading (Vdc)	Wear (in)	RH(%)
7/27/92	1445	-	73	72	- 8.832 (54.5 mils)	0.0	86
	1500	0	Test Started	-	-	-	-
	1600	1	-	132	-	-	-
	1700	2	-	135	-	-	-
	1800	3	-	132	-	-	-
	1900	4	-	127	-	-	-
	2000	5	-	130	-	-	-
	2100	6	-	123	-	-	-
	2200	7	-	122	-	-	-
	2300	8	-	120	-	-	-
	2400	9	-	120	-	-	-
7/28/92	0100	10	-	125	-	-	-
	0200	11	-	>295	-	-	-
	0300	12	-	315	-	-	-
	0400	13	-	375	-	-	-
	0500	14	-	132	-	-	-
	0600	15	-	108	-	-	-
	0700	16	-	100	-	-	-
	0800	17	76	82	-13.772 (82 mils)	0.027	81

*Hourly temperatures were reduced from datalogger chart paper.

Table 7 (Cont.)
TEST DATA TABULATIONS
RUN NO. 4
BEARING NUMBERS 0005 & 0008

BEARING NO. 0008:

Date	Clock Time	Elapsed Time (h)	Ambient Temp(°F)	Bearing Housing Temp(°F)*	Proximitor Reading (Vdc)	Wear (in)	RH(%)
7/27/92	1445	-	73	72	- 8.561 (55.0 mils)	0.0	86
	1500	0	Test Started	-	-	-	-
	1600	1	-	108	-	-	-
	1700	2	-	112	-	-	-
	1800	3	-	115	-	-	-
	1900	4	-	120	-	-	-
	2000	5	-	125	-	-	-
	2100	6	-	120	-	-	-
	2200	7	-	118	-	-	-
	2300	8	-	100	-	-	-
	2400	9	-	105	-	-	-
7/28/92	0100	10	-	112	-	-	-
	0200	11	-	290	-	-	-
	0300	12	-	260	-	-	-
	0400	13	-	325	-	-	-
	0500	14	-	122	-	-	-
	0600	15	-	93	-	-	-
	0700	16	-	93	-	-	-
	0800	17	76	82	-13.700 (86 mils)	0.031	81

*Hourly temperatures were reduced from datalogger chart paper.

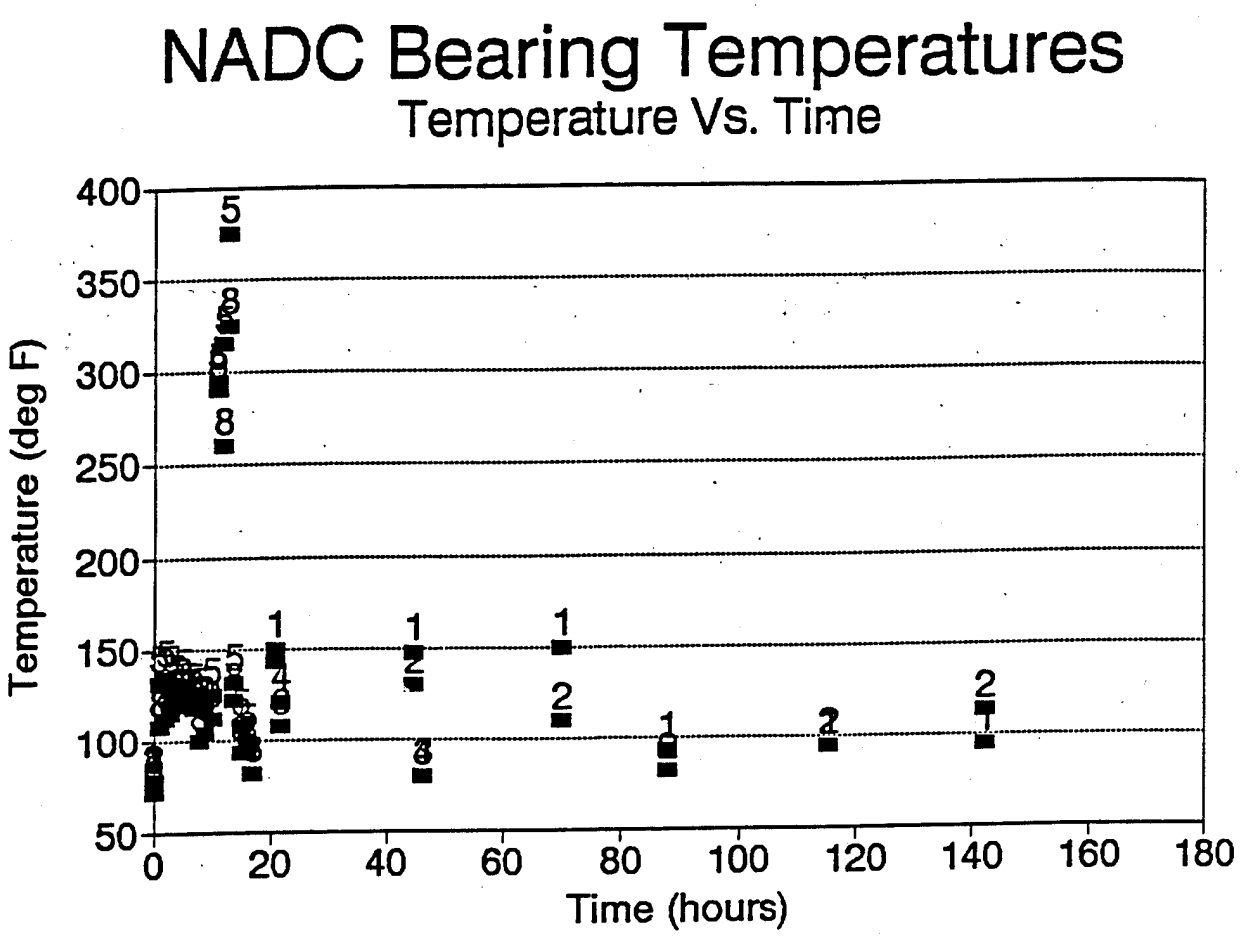


Figure 6. Graph of Temperature vs Time for Failed Bearings.

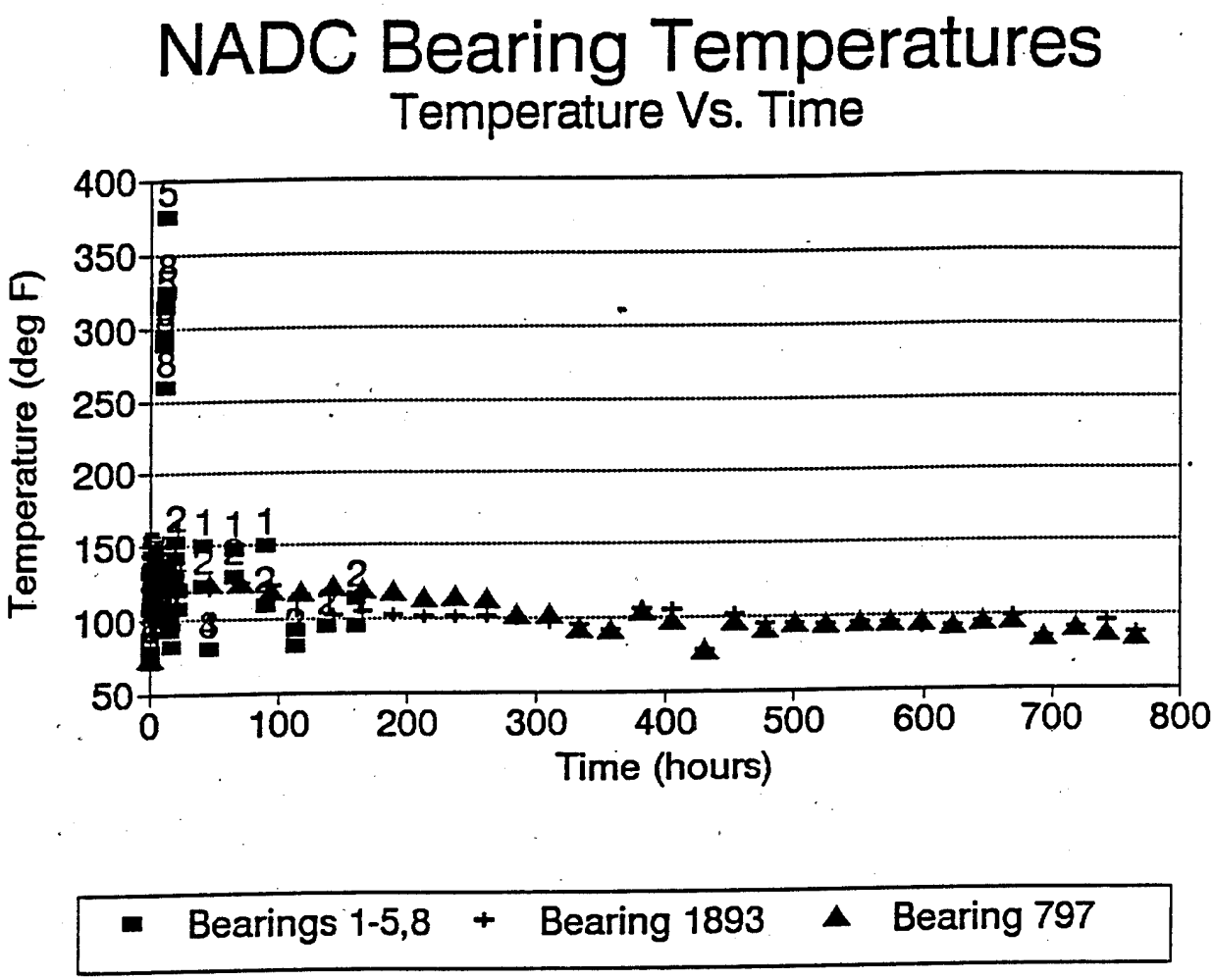


Figure 7. Graph of Temperature vs Time for Failed Bearings and Successfully Tested Field Bearings.

from the bearings. For the same reason, microscopic measurements of the liners could not be performed.

5.5 FAILURE ANALYSES OF THE TEST BEARINGS

5.5.1 Test Data

After the bearing tests were completed, the test data tabulated in Tables 1 to 4 and plotted in Figure 8 were analyzed. Bearings 0001-5 and 0008 were part of the original study. Bearings 00797 and 01893 were submitted by NADC when short failure times were noticed on the initial tests. A failure line of .008 inches is indicated on the graph. The time required for a bearing to wear this amount is the failure time.

Two distinct trends can be noticed from the data. The first trend shows low failure times for bearings 0001,2,3,4,5, and 8. None of these bearings exceeded 143 hours before failure. They were expected to last 800 hours. The second trend shows no failure for bearings 00797 and 01893. Both are of the bearing type in field use.

A graph isolating the failed bearing data is shown in Figure 9. This graph highlights the wide variation in failure times among the failed bearings. This wide variation limits the usable information from the Weibull and statistical analyses.

5.5.2 Weibull Analysis for Bearing Test Data.

The test data was used to estimate the failure time for each bearing. A linear interpolation (bearings 1,2 3,5,8) and extrapolation (bearing 4) was used to estimate the time each bearing would wear .008 inches.

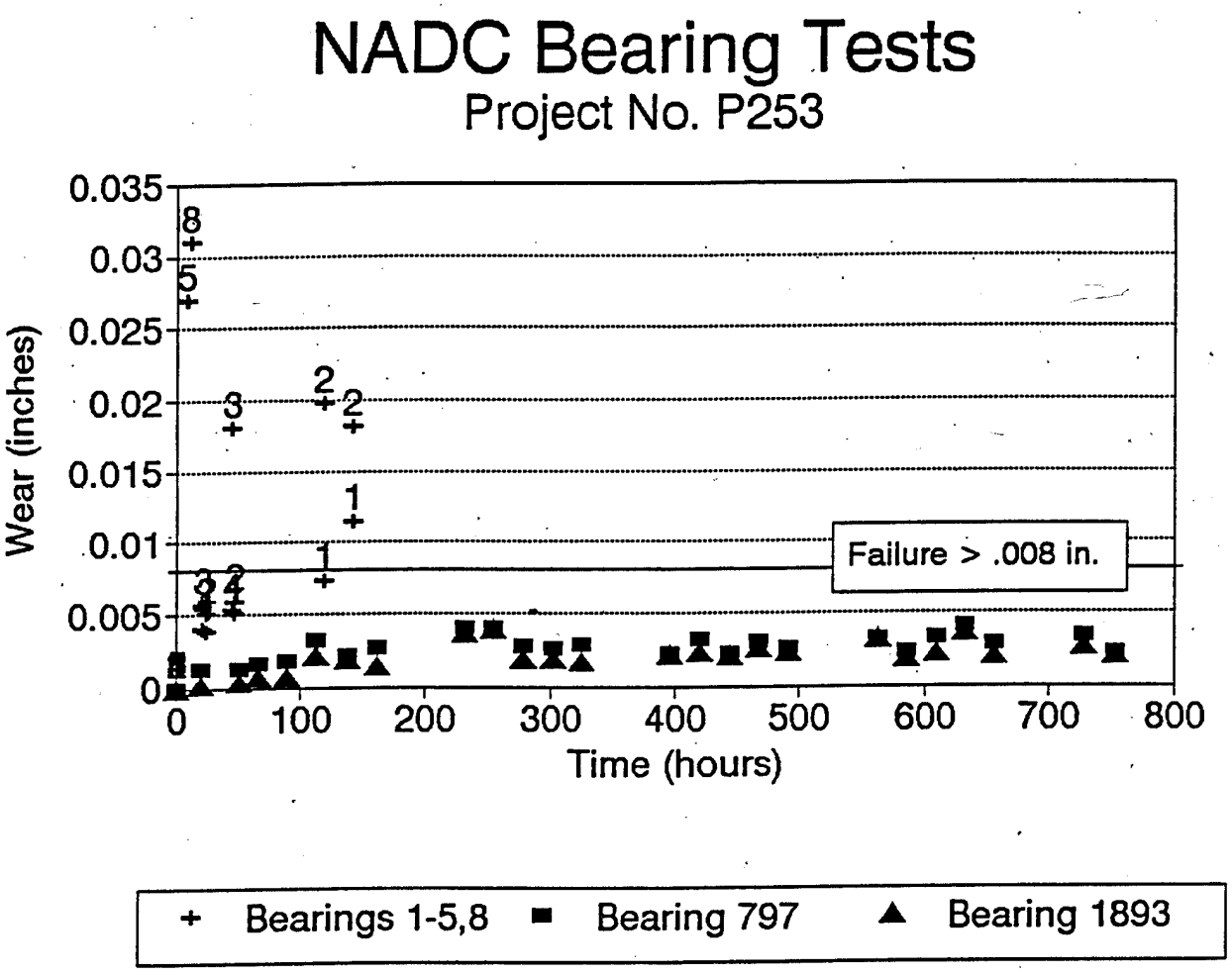


Figure 8. Graph of Bearing Wear vs Time for Failed and Successfully Tested Bearings.

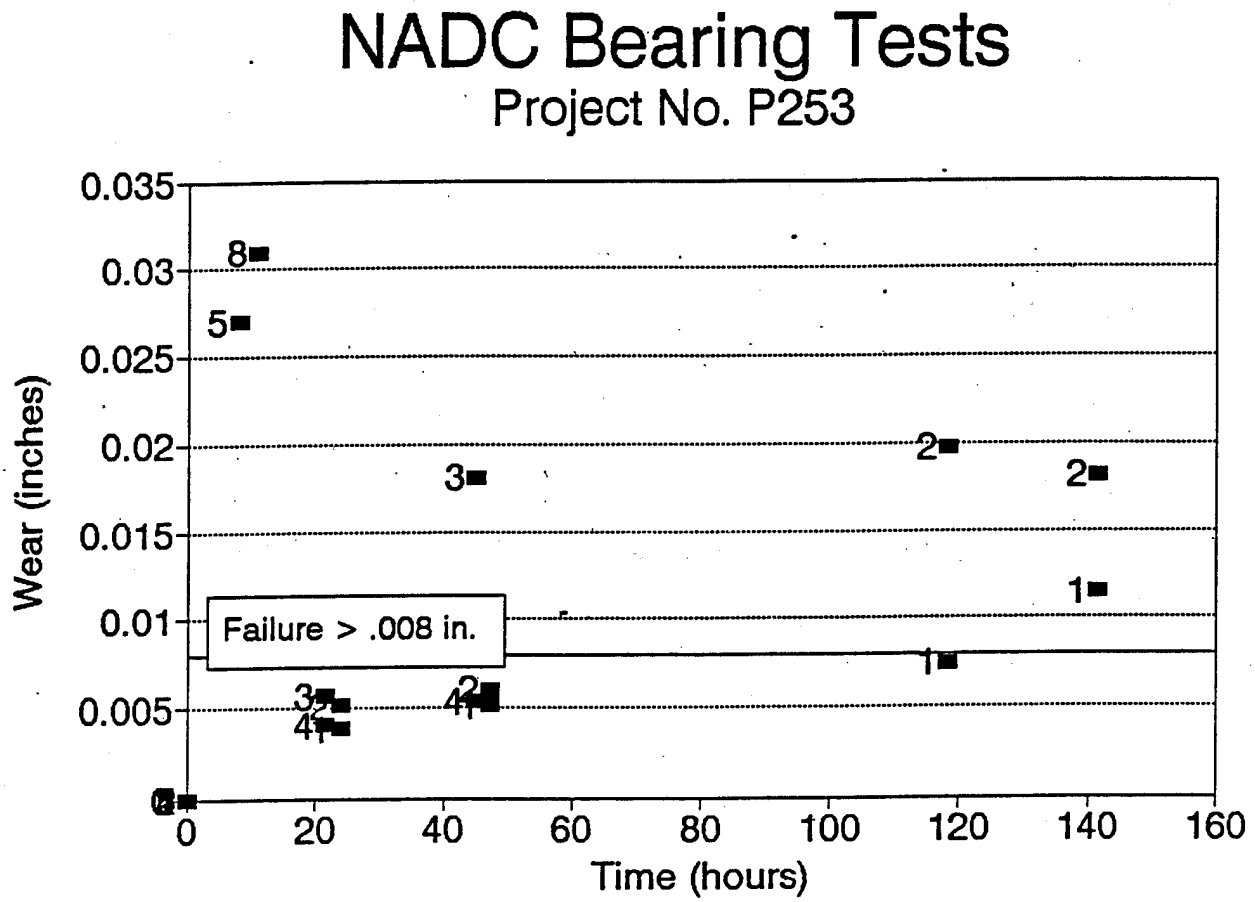


Figure 9. Graph of Bearing Wear vs Time for Failed Bearings 1-5 & 8.

The failure times were ranked and the Weibull distribution (Median Rank) was obtained using Bernard's formula (Table 8). This information was plotted on Weibull paper (Figure 10). By determining the slope of the line and the bearing's mean operating time, the failure mode classification was determined.

A straight line approximation was used to obtain the slope of the Weibull line. This was determined to be 0.68, indicating infant mortality for all the failed bearings (Weibull Analysis Handbook, AFWAL-TR-83-2079, p. 22). The life expectancy (Eta) is determined to be 48 hours.

Based on the wide variation in data and the extremely low failure time of the bearings, it was determined that the log normal analysis would add no additional useful information. Therefore, it was not performed.

The statistical mean of the bearing failure times based on an assumed normal distribution is also 48 hours. The corresponding standard deviation was calculated to be 44.1 hours. This large value of the standard deviation further demonstrates that the failure data is statistically irrelevant.

5.6 DISCUSSION OF ANALYSIS

The wide variation in failure times made the Weibull and statistical analyses of limited usefulness in analyzing the bearing data. However, all data indicates that the life for

Table 8. Failure Time Data for Weibull Analysis

Rank	Bearing No.	Failure Time (Hours)	Median Rank
1	0005	2	.11
2	0008	3	.27
3	0003	25	.42
4	0002	57	.58
5	0004	90	.73
6	0001	120	.89

$$\text{Median Rank} = \frac{i - 0.3}{N + 0.4} \qquad \text{(Benard's Formula)}$$

where

i = Rank

N = Number of Data Points

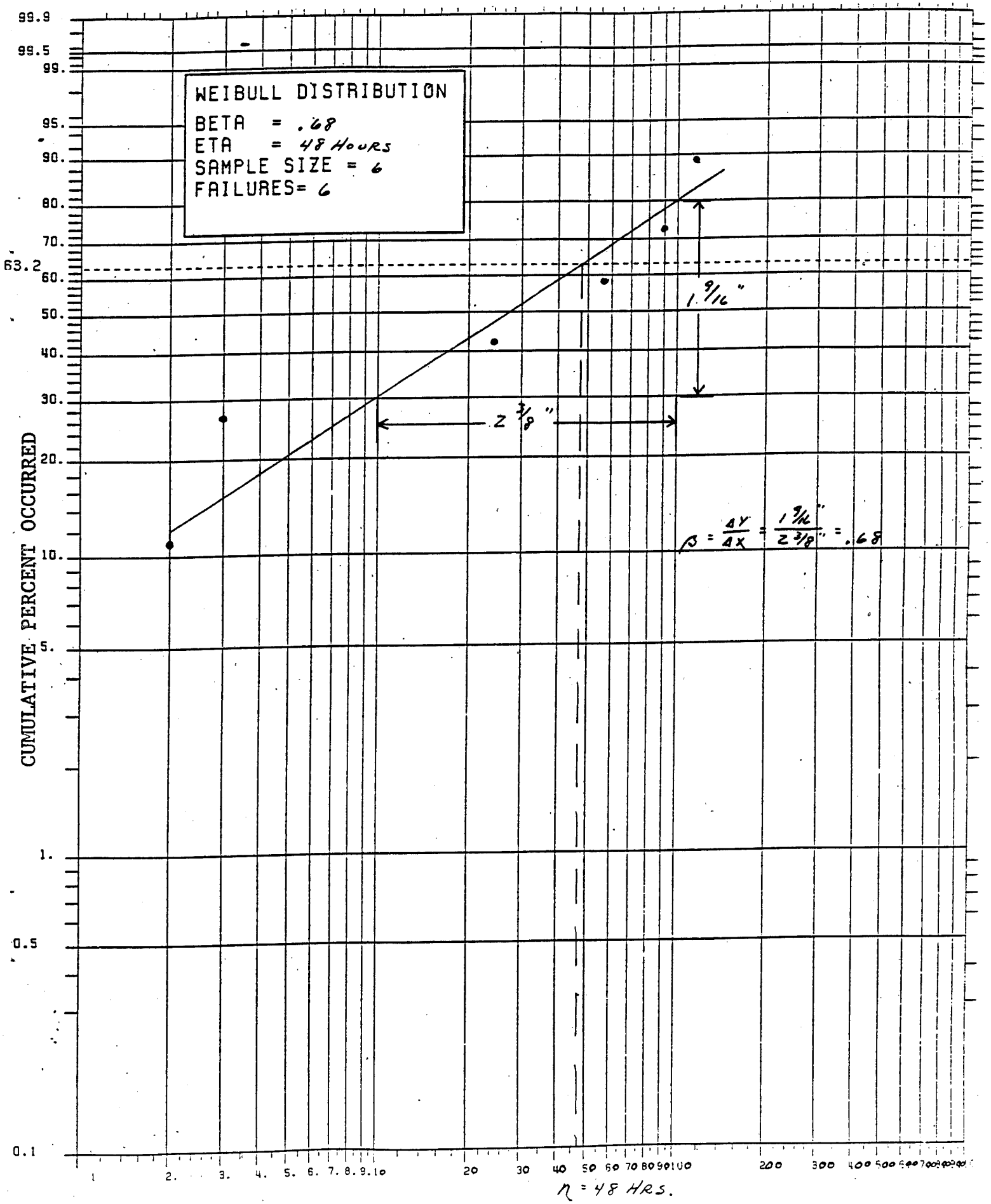


Figure 10. Weibull Graph of Bearing Failure Data.

bearings 0001, 2, 3, 4, 5, and 8 were less than 20% of the expected wear value. The validity of this testing was confirmed by the field bearing test data, which showed these bearings, 00797 and 01893, did not fail.

6.0 SUMMARY AND CONCLUSION

Twenty-two plain spherical bearings were submitted by NADC for testing under simulated helicopter pitch link load/motion conditions. Of the 22 sample bearings, 12 or more were expected to log 9600 hours of testing before encountering wear problems. However, five of the six bearings tested failed prematurely and the sixth bearing was close to failing when the test was terminated. Failure, in all cases, was caused by the plastic liner cracking and working its way out from between the inner and outer parts of the bearings. The bearings, which were expected to perform for an average of 800 hours, failed catastrophically after a maximum of 143 hours of testing.

None of the other sample bearings were Type II tested since the bearings were failing with the lower loads of the Type I tests.

After the first two test runs and four bearing failures, a special test was requested by NADC. Two spherical pitch link bearings, of the same type now being used in present day Naval helicopters, were tested under the same load/oscillation conditions as the four bearings that failed. There was no failure after 763 hours of testing. Furthermore, the maximum wear in these two bearings was only 4.1 mils.

Based on the early bearing failures of the scheduled tests and the unscheduled successful test of the Naval field bearings, it is concluded that the sample bearings are deficient.

APPENDIX A.

LIST OF DATA ACQUISITION INSTRUMENTS

DATA ACQUISITION INSTRUMENTATION LIST

FRC Item No.	Manufacturer	Description	Model No.	Serial No.	Calibration Date Calib'd	Calibration Date Due
5070	FRC Lebow	5000 lb Load Cell	3174-5K	129	10/30/91	10/30/92
5056	Esterline Angus	Multipoint Recorder/ Logger	MRL 488	88340024	Internal calib.	Internal calib.
5040	Fluke	Digital Multimeter	8800A	36076	09/13/91	09/13/92
32-0119	Omega	Digital Thermometer	2161	3290003	11/20/91	11/20/92
32-0002	Hewlett-Packard	Digital Multimeter	3466A	1716A-18181	01/30/92	01/30/93
32-0066	Hewlett-Packard	Universal Counter	5316A	2052A00560	03/25/92	03/25/93
0248	Consolidated Devices	Torque Wrench	15020DIN	None	01/29/92	01/29/93
-	KIMAX	Graduate (100 ml)	20024	None	Not required	
0078	Nicolet	Digital Oscilloscope	1090A	773778	09/17/91	09/17/92
3	Bentley-Nevada	Proximitor Probe	138962	291814	10/30/91	10/30/92
1	Bentley-Nevada	Proximitor Probe	305397	291826	10/30/91	10/30/92

APPENDIX B.

WORK STATEMENT

STATEMENT OF WORK

1.0 Scope. In this developmental testing program the contractor shall conduct various tests on sample tail rotor pitch link bearings supplied by the government. In addition, the contractor shall perform statistical analyses of the endurance test data, summarize all the test data and present the statistical analysis results in a written report.

1.1 Introduction. Helicopter tail rotor blade pitch angles are controlled by a pitch link which is fitted with a bearing at each end. These pitch link bearings typically suffer high replacement rates because of bearing wear. High wear rates are caused by cyclic loading and high speed oscillatory motion between the sliding surfaces of the bearings. The purpose of the test program described by this Statement of Work is to evaluate a new pitch link bearing design.

2.0 Applicable Documents. None.

3.0 Requirements.

3.1 General. The contractor shall conduct a test program to evaluate the performance of plain spherical bearings under simulated helicopter pitch link load/motion conditions. The test schedule is shown in Table I and includes the following tests.

(1) Type I - Cyclic Load Oscillation Wear Test
(2) Type II- Cyclic Load Oscillation Wear Test
(3) Wear Measurement After Removal From Test Machine.

A total of 9,600 bearing test hours is required. The test plan is based on twelve bearings being tested, six in the Type I test and six in the Type II test, with an expected average bearing life of 800 hours. The tests shall be run to bearing failure. If average life is greater (or less) than 800 hours, the number of samples tested shall be reduced (or increased) so as to achieve the required 9,600 bearing test hours. Test conditions, failure criteria, loads, motions, cyclic rates, measurements, and data to be recorded are specified in the test methods below.

Table I - Test Schedule

Test	Sample Number																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Type I	X	X	X	X	X	X							X	X			X	X
Type II							X	X	X	X	X	X			X	X		
Wear Measurement	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

3.2 Detail. The contractor shall perform the following tasks.

3.2.1 General Test Conditions. Except as otherwise specified in a specific test, all measurements and tests shall be made at the following conditions:

a. Temperature: All tests shall be conducted at a room temperature of $75^{\circ} \pm 15^{\circ}$F. Actual ambient temperature shall be recorded during all tests.

b. Barometric pressure: Local ambient

c. Relative humidity: 90 percent or less

3.2.2 Cyclic Load Oscillation Wear Tests. The bearing shall be installed in a heat treated steel housing (see Figure 1) with a 0.0005 to 0.0015 inch interference fit. The bearing outer ring side face shall be indelibly marked or engraved at the maximum load location to facilitate accurate wear measurement after removal from the test machine. A standard close tolerance aircraft bolt or pin (125,000 psi minimum) shall be used as a shaft for the bearing. The clearance between the bearing I.D. and bolt (or pin) shall not be greater than 0.0015. The bearing shaft shall be placed in double shear with a minimum of bending and shall be so assembled and secured as to assure that during the test all relative motion shall be between the ball and the outer ring.

The test setup shall include a means to measure the wear of the bearing at intervals throughout the test. The bearing wear measurements shall be made at the point of maximum load application with the bearing under a predetermined measurement load. The specific measurement load value is to be defined by the contractor but shall not be changed during a test. The measurement load chosen shall be not greater than the maximum test load nor less than 200 pounds. The wear shall be recorded at time intervals close enough to produce a graph showing wear in thousandths of an inch versus life in hours. There shall be a minimum of one reading per normal work day. The bearing housing temperature shall be measured at the location indicated in Figure 1. The housing temperature shall be recorded at intervals close enough to produce a graph of temperature versus hours. Prior to and upon completion of the test, the breakaway torque of the bearing under the "measurement load" shall be measured and recorded.

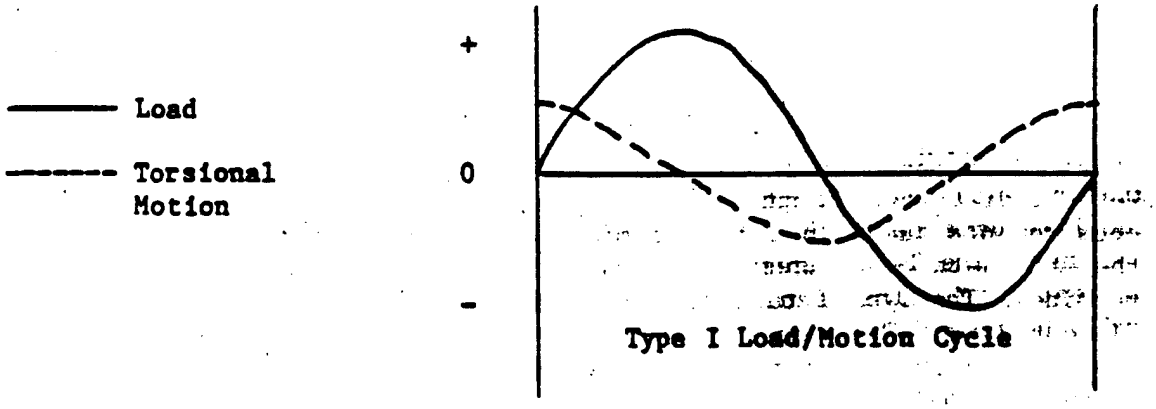
The Type I and Type II tests both require that the load shall be applied sinusoidally placing the shank of the bearing housing alternately in tension and compression. Paragraph 3.2.2.1 provides details about the loads, motions and test conditions for the Type I and Type II tests. The test load is reacted by the shaft (pin) through the bearing bore. The inner member of the bearing shall be oscillated relative to the outer member simultaneously with application of the load.

After installation in the machine, but before starting the test, the measurement load shall be applied statically to the bearing for 15 minutes. After this time the wear indicating device shall be set to zero. Once this "zero wear" reference datum is established the test may be started.

As the ball of the bearing is oscillated, the bearing shall be contaminated with distilled water applied at the juncture of the upper side of the ball and outer ring. The water shall be applied once per hour in the amount of 15 ml (1/2 fl. oz.) to 45 ml (1-1/2 fl. oz.) to each side of the bearing. Due to the length of the tests, it is permissible for the test machine to run unattended overnight and up to three successive days provided that the water contamination is applied at least six but not more than ten times per calender day of attended testing for a minimum of thirty and a maximum of sixty times per calendar week.

3.2.2.1 Test Conditions. Specific test conditions are as follows:

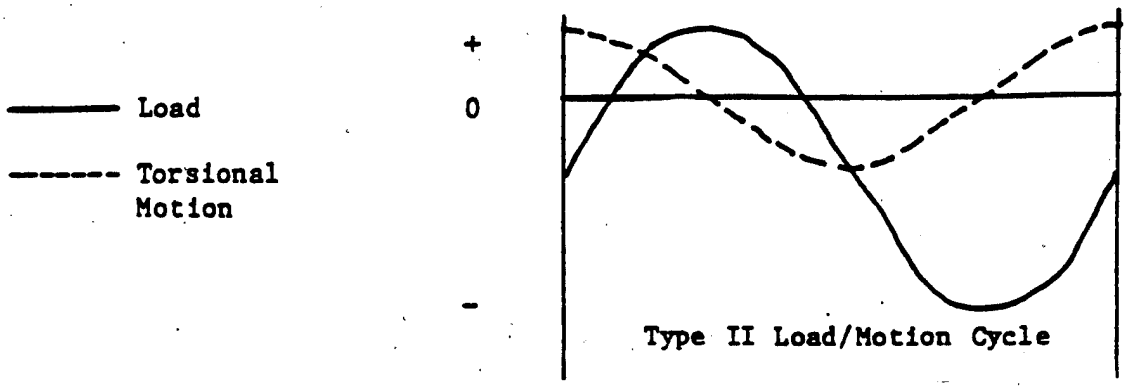
Cyclic Rate:	700 cycles per minute (Type I and II)
Phase Relationship:	Radial load and angular motion are 90 degrees out of phase (Type I and II)
Type I Load:	± 900 pounds cyclicly reversing (Type I) Positive load = housing shank in tension.
Angular Motion Torsional:	±10 degrees (Type I)



Type I Load/Motion Cycle

Type II Load: -600 ± 1000 pounds cyclicly reversing (Type II)
Positive load = housing shank in tension.

Angular Motion
Torsional: ±6 degrees (Type II)



Type II Load/Motion Cycle

3.2.2.2 Failure Criteria. The bearing shall be considered to have failed when the indicated wear exceeds 0.0080 inch.

3.2.3 Wear Measurement After Removal From Test Machine. At the completion of the test the bearing shall be metallurgically mounted and sectioned through the maximum load zone. The liner material remaining shall be measured microscopicly and the wear calculated using the formula:

Wear = Initial liner thickness minus the amount of liner remaining.

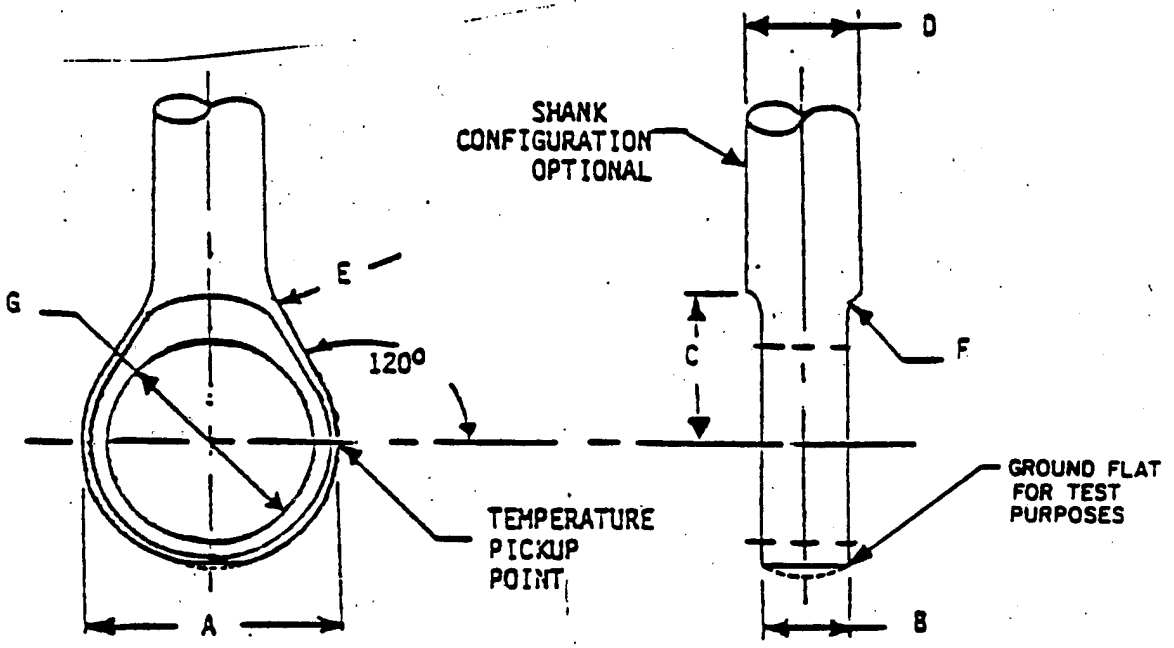
3.2.4 Test Equipment. The contractor shall provide all test equipment and test fixtures. The list of equipment shall be supplied to the government for approval (CDRL A001).

3.2.5 Government Furnished Materials. The government shall supply all bearing test samples 30 DAC. The contractor shall mark each bearing with an indelible identification so that the bearing may be matched with its test data at a future time. The contractor shall return the test bearings within sixty days of completion of cyclic load testing to the Naval Air Development Center, Code 60611, Warminster, PA 18974-5000.

3.2.6 Statistical Analysis of Test Data. The contractor shall perform statistical analyses of the endurance test data using both log-normal and Weibull distribution techniques. The bearing life data generated from measurements taken in the test machine shall be analyzed separately from the life data based upon measurements made after removal from the test machine. The Type I test data shall be analyzed separately from the Type II test data. The mean, standard deviation and correlation coefficient shall be calculated for each set of data and tabulated in the final report.

The sets of data shall be plotted on statistical graph paper. The plots shall include 90% confidence bands and determination of L10 and L50 life values. The plots shall be included in the final report.

3.2.7 Test Plans and Reports. A test plan shall be submitted 30 DAC in accordance with requirement A001 of the attached Contract Data Requirements List (CDRL). A progress report shall be submitted 120 DAC in accordance with CDRL requirement A002. In addition, upon completion of testing, a final report shall be prepared in accordance with CDRL requirement A003. The final report shall include tabulations of all the test data and statistical analyses of the endurance test data. The statistical analyses shall be performed in accordance with requirements of paragraph 3.2.6 of this Statement of Work.



A (Dia) ±.010	B	C ±.010	D (Dia)	E (Radius) Min.	F (Radius) Min.	G (Dia)	Test Bearing O. D.
2.062	.540 .528	1.187	optional	1.00	.125	1.5615 1.5610	1.5625 1.5620

Housing Material: PH 13-8 Mo
Heat Treatment: Condition H 1000

FIGURE 1. Bearing Housing Dimensions